Incorporating Space-borne Measurements to Improve Air Quality Decision Support Systems

Arastoo Pour Biazar[1], Richard T. McNider[1], Mike Newchurch[1], Maudood Khan[2], Bill Koshak[3]

Collaborators

Gary Jedlovec[3], Jonathan E. Pleim[4], Xiong Liu[5], Greg Osterman[6], Daewon W. Byun[7*], Kelly Chance[5], Thomas P. Kurosu[5]

1. University of Alabama in Huntsville (UAH)
2. University Space Research Association (USRA)
3. National Aeronautics and Space Administration (NASA)
4. USEPA/ORD/NERL/AMAD/AMDB
5. Harvard-Smithsonian Center for Astrophysics
6. JPL
7. NOAA

* Deceased, 9 February 2011

PROJECT SUMMARY

TOPIC: **Incorporating Space-borne Measurements to Improve Air Quality Decision Support Systems**

POP: 10/1/2009 – 9/30/2013 (ROSES-08)

PI: Arastoo Pour Biazar (University of Alabama – Huntsville)

Co-Is: Dick McNider (UAH), Mike Newchurch (UAH), M. Khan (USRA), Bill Koshak (NASA)

Partners: USEPA, Texas Commission on Environmental Quality (TCEQ), Georgia Environmental Protection Division (GA-EPD)

NASA Assets: NASA's GOES Product Generation System; OMI ozone, formaldehyde, and nitrogen dioxide observations; MODIS Aerosol Products; NASA Lightning NOx-production Model (LNOM)

Objective: To employ satellite products to improve the air quality management Decision Support Tools (DSTs) used in defining emission control strategies for attainment of air quality standards.

What is SIP

The State Implementation Plan (SIP) Decision Making Process

- Classification: Once an area exceeds the National Ambient Air Quality Standard (NAAQS) for a criteria pollutant (e.g., O3, NO2, SO2, particulate matter) and is listed by the USEPA as **non-attainment** the state must develop a plan or strategy to lower the pollutant levels to meet the NAAQS.
- Design Period: A design day or design period is selected (usually the period when the highest pollutant levels occur).
- Best Modeling Practice: Model simulations are carried out to determine whether the model can reasonably replicate the atmospheric conditions for such episode and the observed pollutant values for that period.
- Emissions Reduction: Next various emission reduction scenarios in these models are carried out to determine the most efficient strategy for meeting the air quality standards for the design period. **This defines the SIP**.

Control Strategy Decisions Made With WRF/CMAQ Can Amount to Billions of Dollars

- Under the Southern Oxidant Study it was estimated that SIP control decisions involved $5 billion for 6 southeastern states

- In Texas the cost of the ozone SIP for Houston alone was estimated to be over $1 billion.

- Nationally these SIPs amount to ten's of billions in control costs (http://www.epa.gov/oar/sect812/feb11/fullreport.pdf).

Design Period Simulations

It is imperative to reproduce the observed atmosphere. Model uncertainties translates into uncertainties in emission control strategy which has significant economic consequences.

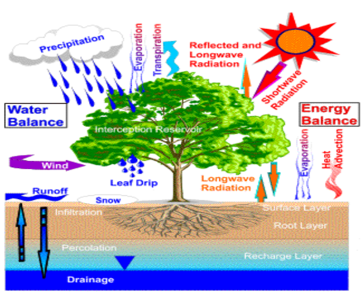
Physical Atmosphere

Models: WRF, MM5, RAMS
Recreates the physical atmosphere (winds, temperature, precipitation, moisture, turbulence etc) during the design period

Clouds and microphysical processes

Atmospheric dynamics

Boundary layer development



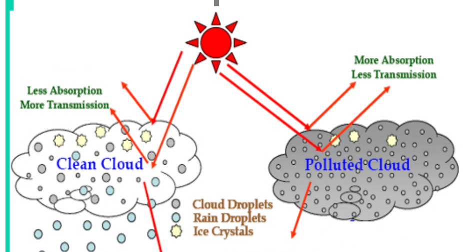
Fluxes of heat and moisture

LSM describing land-atmosphere interactions

Winds, temperature, precipitation, moisture, surface properties and fluxes

Chemical Atmosphere

Models: CMAQ, CAMx
Recreates the chemical atmosphere both the pollutant of interest and precursor chemicals

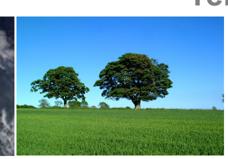


Heterogeneous chemistry, aerosol

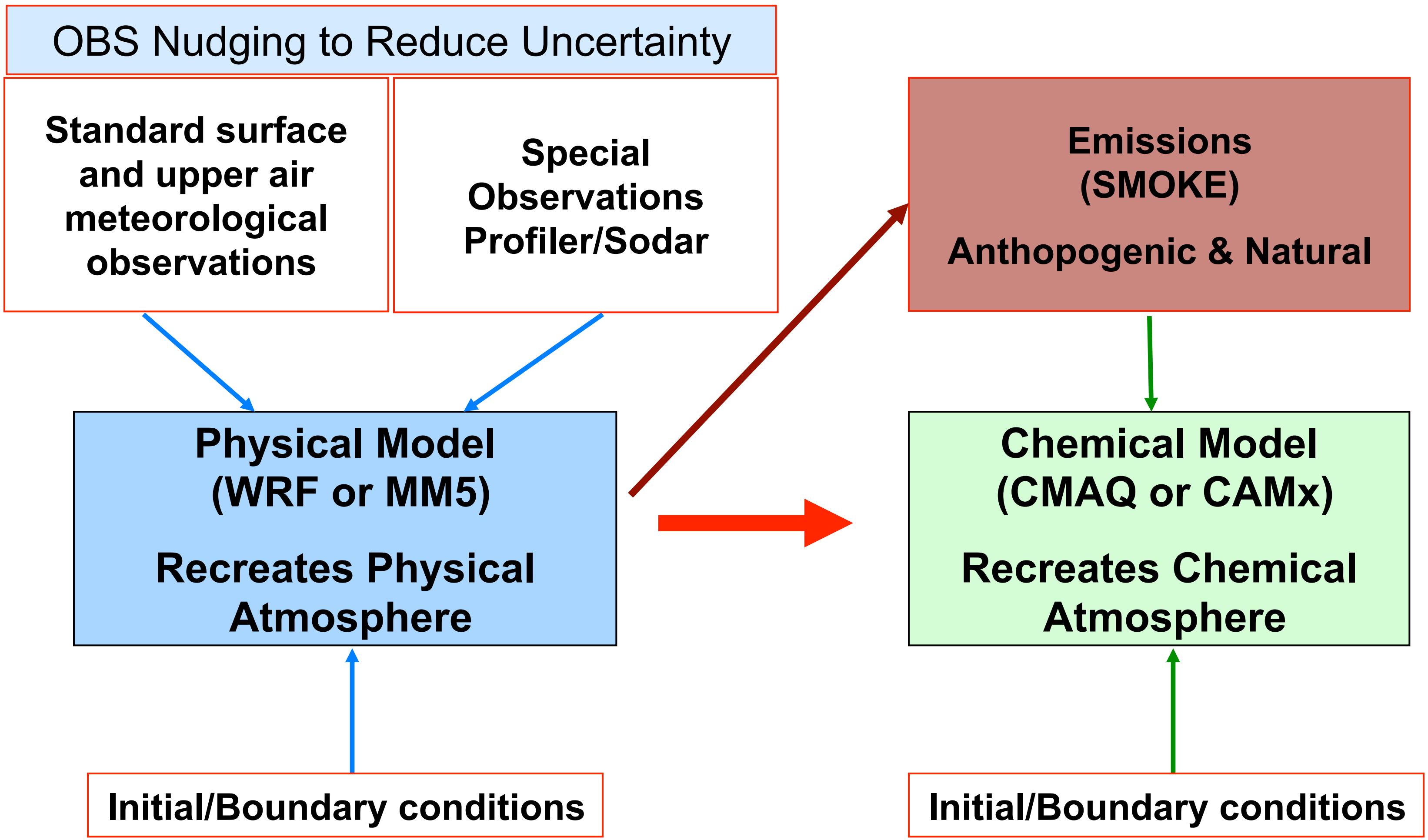
Transport and transformation of pollutants

Photochemistry and oxidant formation

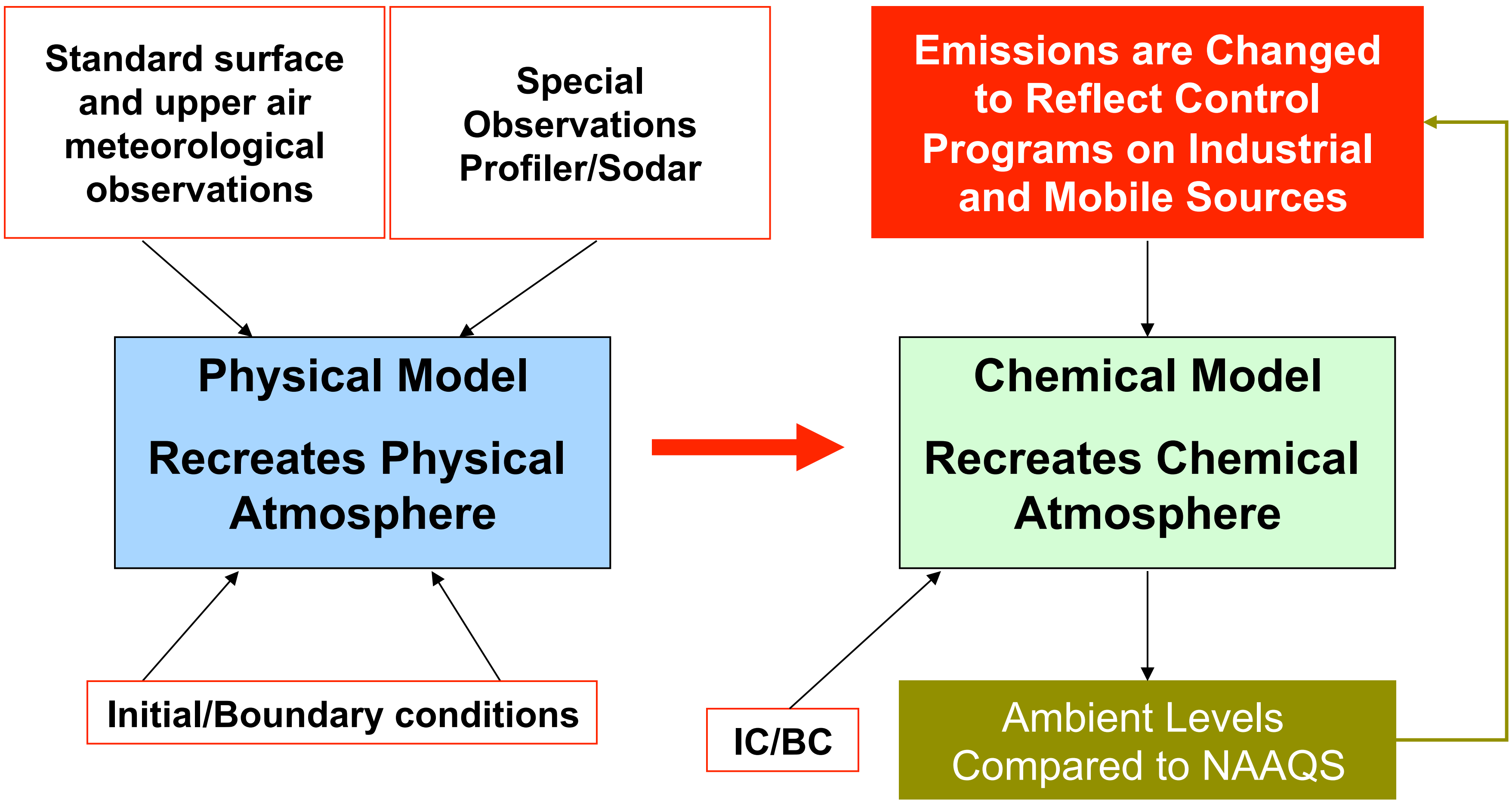
Natural and antropogenic emissions, Surface removal



Design Period Simulations – Inputs



Control Strategy Simulations - Inputs



Impact of Physical Atmosphere on SIP Control Strategies

Clouds:

- Impact photolysis rates (impacting photochemical reactions for ozone and fine particle formation).
- Impact transport/vertical mixing, LNOx, aqueous chemistry, wet removal, aerosol growth/ recycling and indirect effects.

Temperature:

- impacts biogenic emissions (soil NO, isoprene) as well as anthropogenic evaporative losses.
- Affects chemical reaction rates and thermal decomposition of nitrates.

Moisture:

- Impacts gas/aerosol chemistry, as well as aerosol formation and growth.

BL Heights:

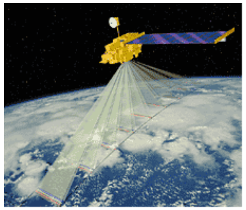
- Affects dilution and pollutant concentrations.

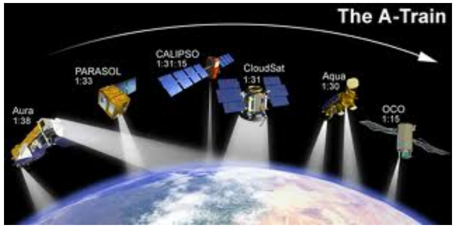
Winds:

- Impacts transport/transformation

Design Period Simulations – Satellite Inputs

Retrospective – Data Assimilated for all Integration Period





Geostationary Satellite •Insolation •Cloud Properties •Skin Temperature	MODIS •Surface emissivity •Surface albedo •Skin temperatures	Satellite derived Cloud properties for photolysis rates	Satellite trace gas and aerosol observations

ASSIMILATION

Physical Model

Recreates Physical Atmosphere

Chemical Model

Recreates Chemical Atmosphere

Geostationary and Polar Orbiting Observations for Evaluation

Specific Objectives

In This Project Satellite Data Will Be Used to Improve the Quality and Accuracy of Retrospective Baseline Simulation in Which Proposed SIP Emission Reductions Are Tested

- **Improving Model Location and Timing of Clouds:** Clouds have a profound role in photolysis activity, boundary-layer development, and deep vertical mixing of pollutants and precursors. Satellite products will be utilized to improve model cloud simulation.

- **Utilization of NASA Lightning NOx-production Model (LNOM):** This activity utilizes LNOM to account for Lightning NO Production (LNOx) in convective clouds.

- **Satellite Trace Gas/Aerosol Utilization:** This activity improves chemical transboundary and initial conditions in the air quality model. The satellite products such as MODIS aerosol and newly available OMI ozone profiles can significantly impact the realization of the chemical state of the atmosphere.

ARL PROGRESS

Improved Characterization of Clouds			
	Year 1	**Year 2**	**Year 3**
Starting ARL	2	3	4
Ending ARL	3	4	5

DST: WRF/CMAQ Modeling System

Year 1: Variational technique, multiple regression code, and WRF baseline simulations were performed.

Year 2: The technique was integrated in WRF modeling system.

Year 3: ***ARL 5: Application components integrated into a prototype system and potential to improve the decision-making activity has been determined and articulated.***

The technique was integrated into the DST, tested, evaluated, and demonstrated improvement in cloud simulation.

(Due to feedback from TCEQ, the approach was revised to make the technique and the procedures simpler and more efficient to be used in an operational setting.)

ARL PROGRESS –

Trace Gas/Aerosol Assimilation

ARL 4: *Components of eventual application system brought together and technical integration issues worked out*

- OMI ozone retrievals and MODIS aerosol products were successfully incorporated in MM5/CMAQ air quality modeling system and improvements were demonstrated (Pour Biazar et al., 2011; Wang et al., 2011).

- We are in the process of utilizing lidar measurements to complement/refine the OMI retrievals (Kuang et al., 2010).

ARL PROGRESS –

LNOM Activity

ARL 4: *Components of eventual application system brought together and technical integration issues worked out*

- The approach for LNOM LNOx calculations went through several revisions. The final version has been posted (http://lightning.nsstc.nasa.gov/data/index.html#LNOM_DATA) for a broader distribution to the user community.

- The technique and its first application within WRF/CMAQ have been documented in Koshak et al., 2012.

SCHEDULE / MILESTONES

Major Tasks	FY10	FY11	FY12	FY13
Cloud Dynamical Support, Implementation/Test & Evaluation/Transition		TCEQ Test/Feedback	Revised and Re-Evaluated	
OMI/TES ozone and MODIS aerosols, Implementation/Test & Evaluation			Implemented in CMAQ, Paper Published	
Lightning Generated Nitrogen Oxide from LNOM, Implementation/Test & Evaluation		Data Released to Public, Paper Submitted *		
Website Development for Dissemenating Tools & Data				
Training Workshop for User Community			Scheduled for Nov. 7-8	
Benchmarking (multiple activities)		Ozone/Aerosol, Cloud	LNOM, Cloud	
Transition Activities (CMAS, EPA, TCEQ)			CMAS Activity Started	

* http://lightning.nsstc.nasa.gov/data/index.html#LNOM_DATA

Completed
Ongoing
Future

BUDGET

Total Awarded (FY10-FY12)	Total Expended as of 7/31/2012	Subcontract to CMAS	Balance
$735,218	$543,860	$52,000	$139,358

- Due to the delay in receiving the third year funding, there is a larger balance remaining for this project. However, due to user workshop cost and the fact that we are devoting more resources to this project in order to stay on schedule, the balance will be expended at a faster rate.
- The total funding (obligated) for the UAH part of this project is $735,218 and as of 7/31/2012, $543,860 has been expended. Please note that the sub-contract for CMAS ($52K) is not showing in the "Total Expended" figure since the paperwork was finalized in August.
- Due to the importance of this work to TCEQ's regulatory activities, TCEQ has been providing complementary funding ($350K) for the cloud correction component of this project.
- There is now a cooperative agreement between TCEQ and UAH.

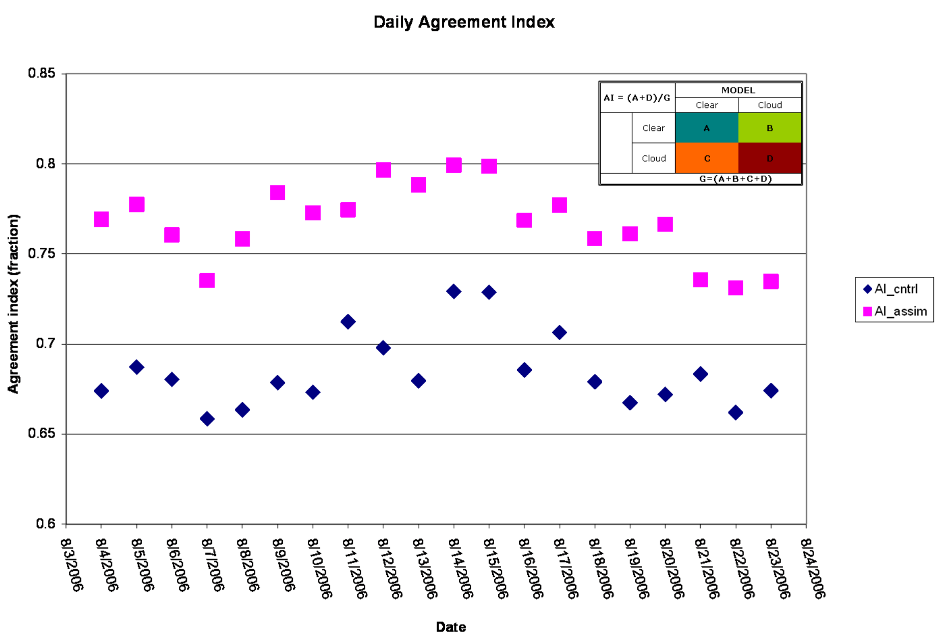
RISKS & ISSUES

- The quality and quantity of GOES data products has been a problem.
  - We are developing a stand-alone retrieval system to be able to address this issue for SIP study periods
- Our ground station will not be compatible with GOES-R.
  - We are planning to use a fast data link to receive near-real-time data from NESDIS.
- Due to feedbacks from TCEQ, our cloud adjustment technique was revised to make it easier for operational use by state agencies.
- The disparity between surface observations and OMI ozone observations for the boundary layer needs to be investigated.
- Easy access to data and tools (for manipulation and re-mapping satellite data) remains a major concern for the user community.
  - To address this issue, we are offering workshops and planning to have more presentations on the use of the data and techniques.

There seems to be a need for some expert support in order to have a sustainable use of satellite data in DSS.

SUMMARY of PROGRESS – Cloud Correction

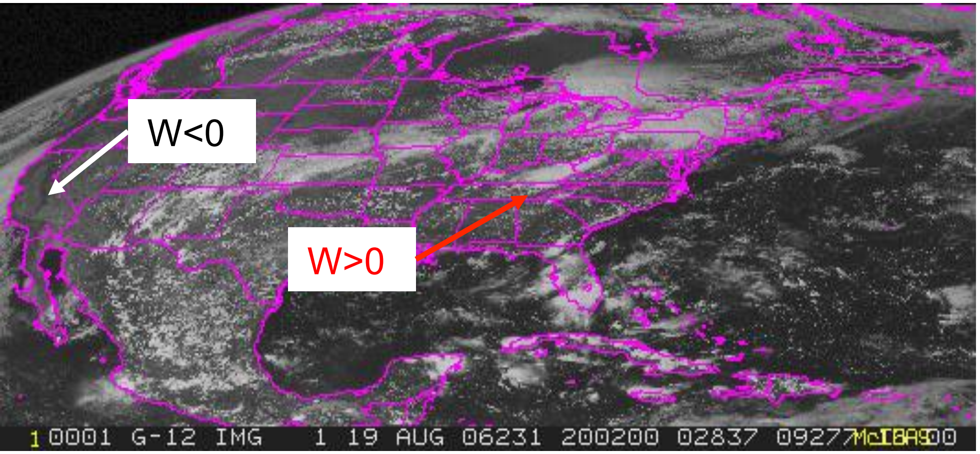
- Improved Characterization of Clouds
  - The technique was ported from MM5 to WRF modeling system
  - The technique has been revised twice to address user group's concern about the feasibility of the technique to be used in regulatory operational setting with limited resources.
  - Due to the importance of this work to SIP applications, TCEQ has been providing complementary funding for this work.



Model performance with respect to cloud simulation was improved by 7-10% for August 2006 as measured by Agreement Index.

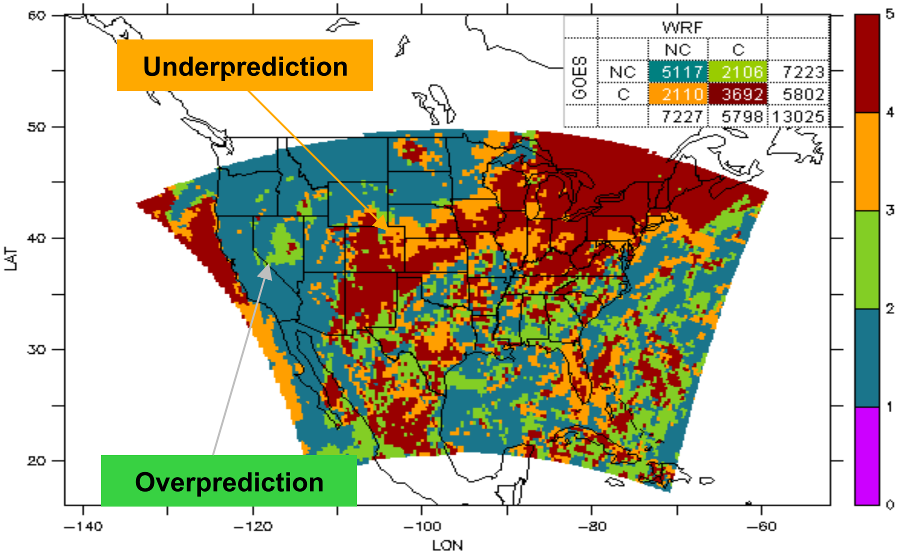
Cloud Correction: Fundamental Approach

Satellite



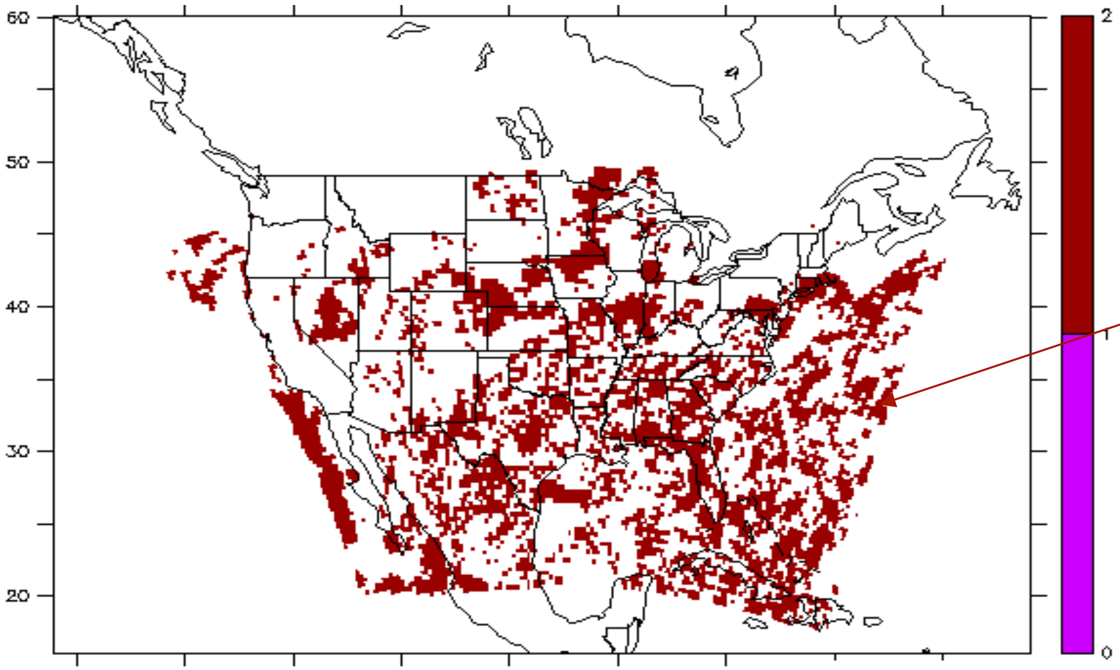
0.65um VIS surface, cloud features

Model/Satellite comparison



- Use satellite cloud top temperatures and cloud albedoes to estimate a **TARGET VERTICAL VELOCITY (Wmax)**.
- Adjust divergence to comply with Wmax in a way similar to O’Brien (1970).
- Nudge model winds toward new horizontal wind field to sustain the vertical motion.
- Remove erroneous model clouds by imposing subsidence (and suppressing convective initiation).

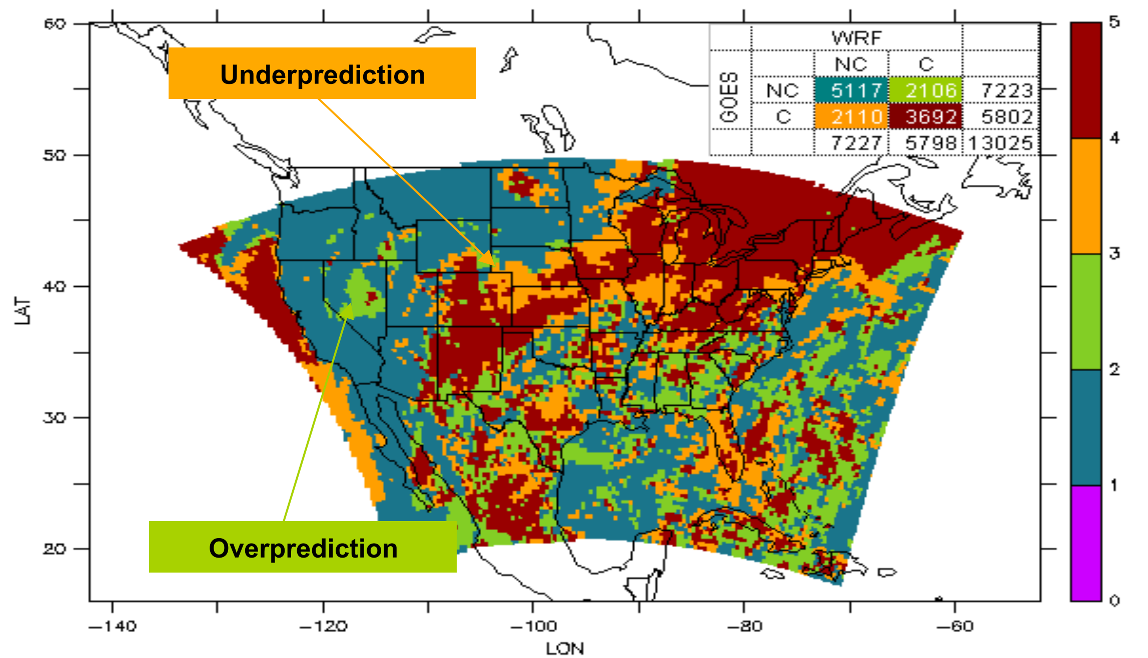
Cloud Correction: Identifying Areas of Under-/Over-prediction for Correction



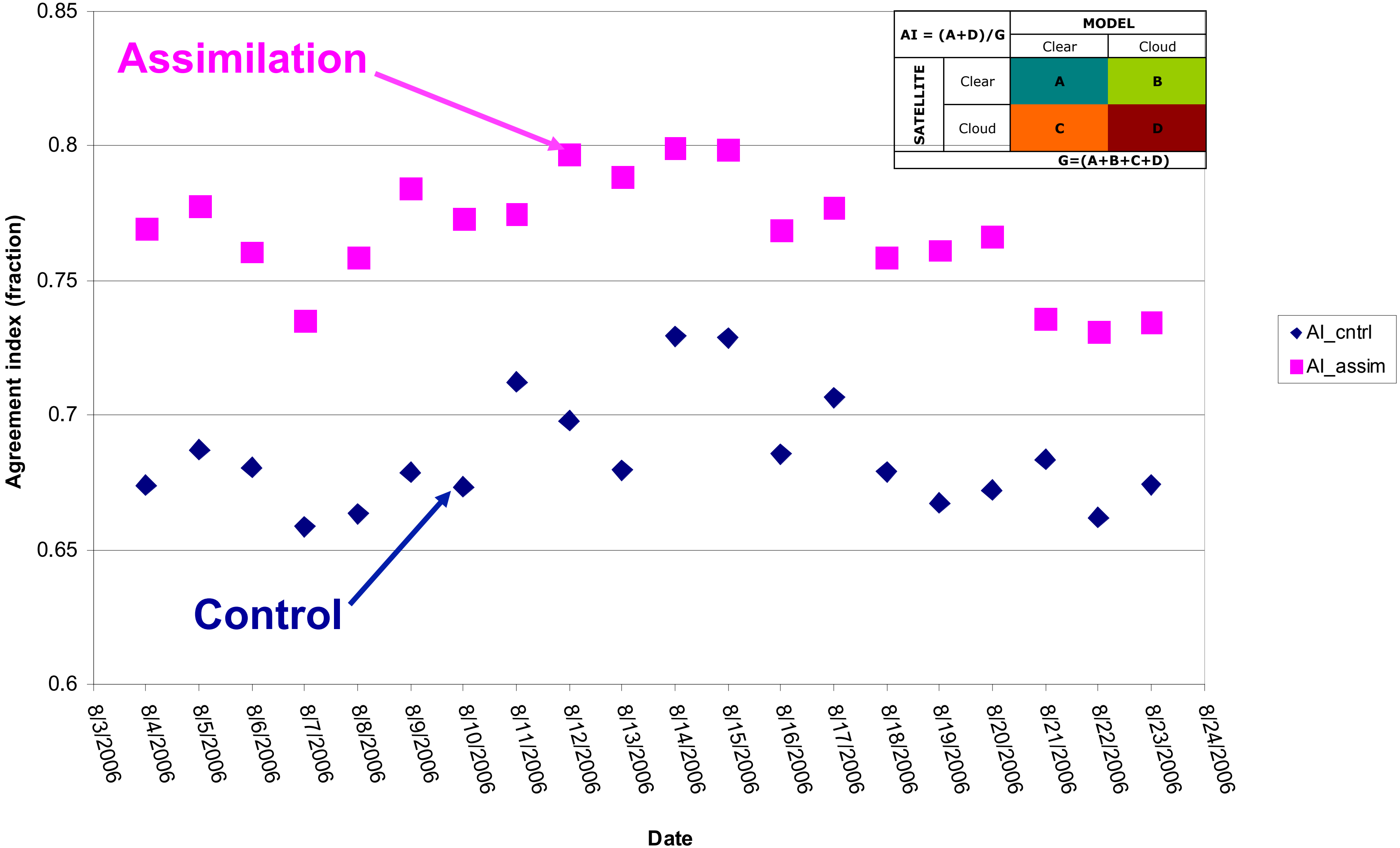
Areas of disagreement between model and satellite observation

A contingency table can be constructed to explain agreement/disagreement with observation

AI = (A+D)/G		MODEL	
		Clear	Cloud
SATELLITE	Clear	A	B
	Cloud	C	D
		G=(A+B+C+D)	

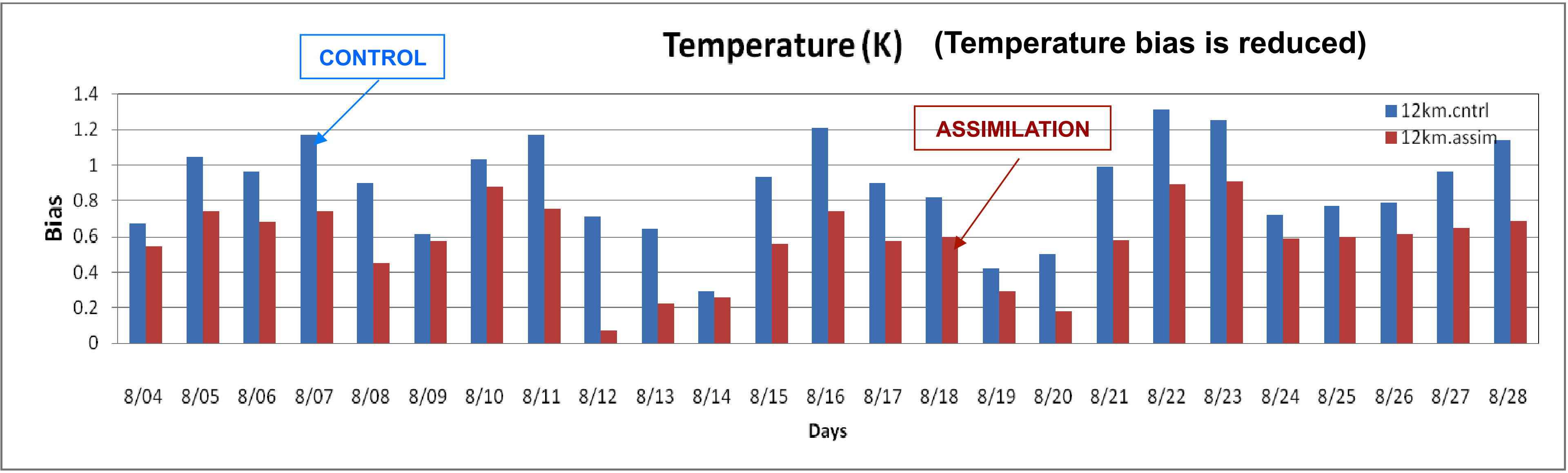


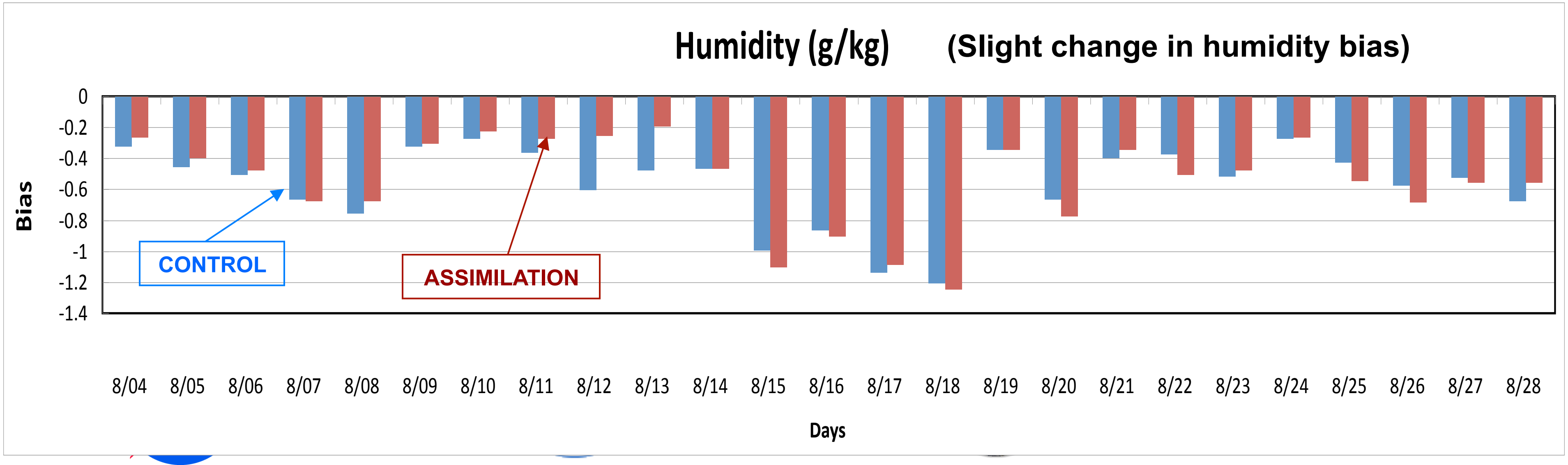
Cloud Correction: Agreement Index = (# of cloudy/clear grids in agreement) / (Total # of grids)



Agreement index increased by 7-10%

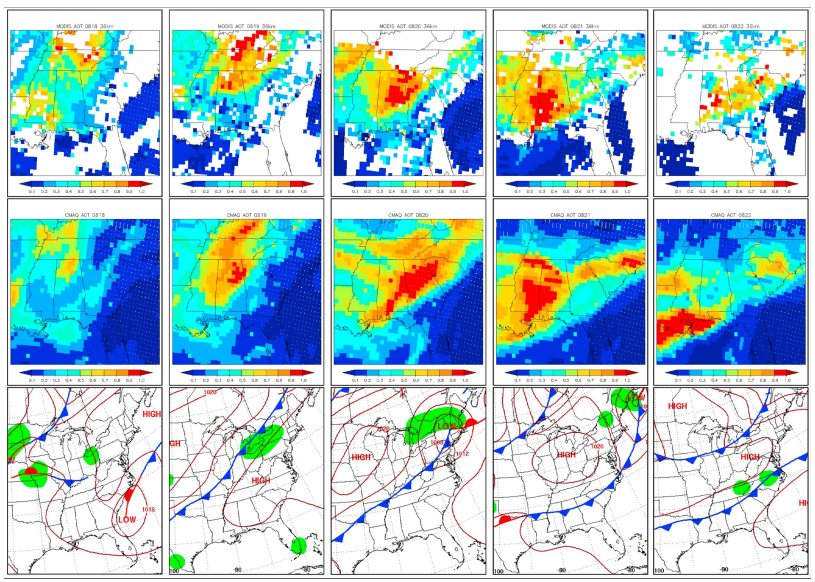
The Impact on Surface Temperature and Humidity



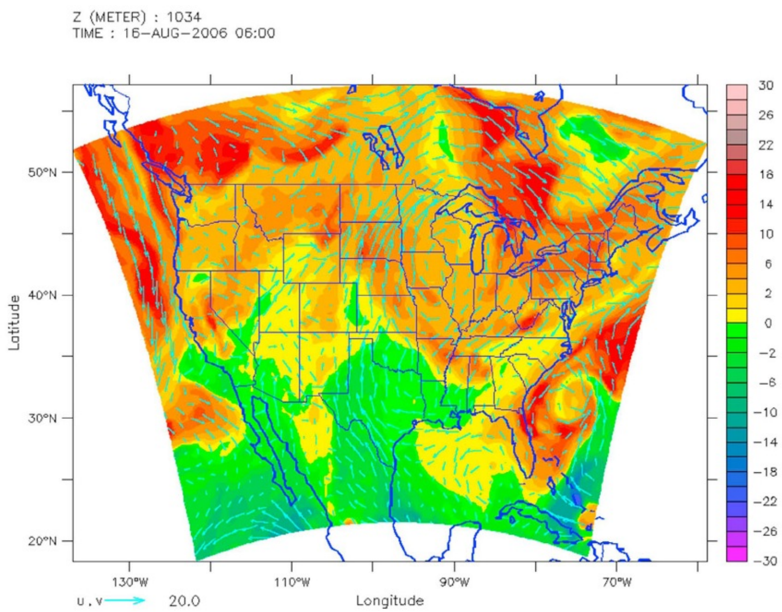


SUMMARY of PROGRESS – Satellite Trace Gas/Aerosol

- Utilization of OMI ozone and MODIS Aerosol products
  - The observations were successfully incorporated in CMAQ
  - The improvements for SIP applications were documented in Pour-Biazar et al., 2011, and Wang et al., 2011.



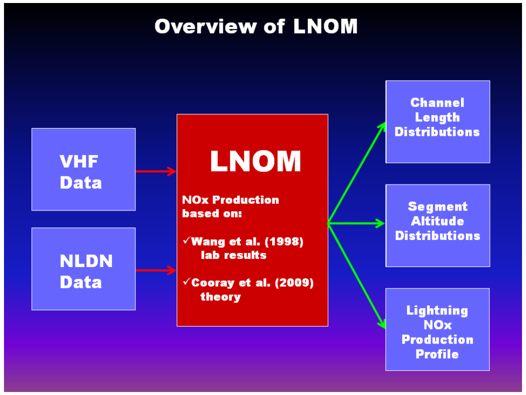
Incorporation of MODIS aerosol products in CMAQ Substantially reduced model error with respect to PM2.5 simulation.
(Adapted from Pour-Biazar et al., 2011)

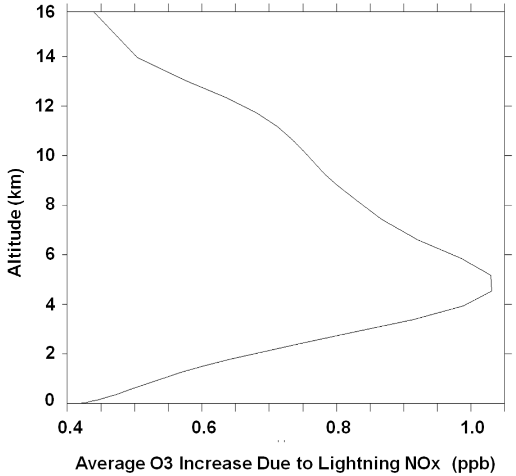


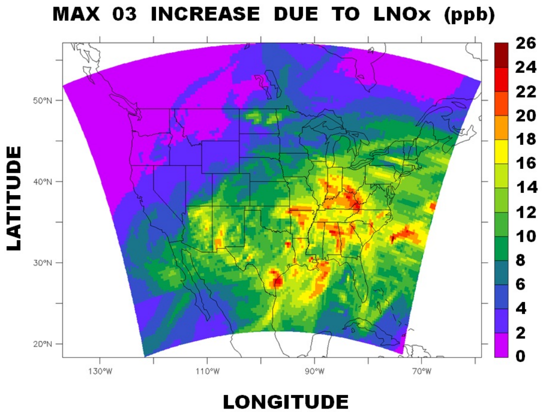
The impact of incorporating OMI observations in CMAQ simulation on the boundary layer ozone for August 16, 2006.
(Adapted from Pour-Biazar et al., 2011)

SUMMARY of PROGRESS – LNOM LNOx Activity

- LNOM LNOx Activity
  - The method and its first application within WRF/CMAQ have been documented (Koshak et al., 2012).
  - Simulations over 4 summers are underway, quantifying the model error due to lack of LNOx in default CMAQ configuration.
  - The data and documentations are now available at (http://lightning.nsstc.nasa.gov/data/index.html#LNOM_DATA)







(Adapted from Koshak et al., 2012)

Remaining Tasks

- User Workshop
  - Working with CMAS, a user workshop is scheduled for November 7-8, 2012, to train individuals from the State and local regulatory community and to the private environmental consulting community.
- Finish benchmarking activities:
  - Finish the evaluation of cloud adjustment technique.
  - Work with EPA and TCEQ for independent evaluation of tools and techniques.
  - Finish LNOM/CMAQ evaluation.
- Upgrade the current web based data delivery system to accommodate tools and documentations from this project.
- Work with CMAS for distribution of models, tools, and documentations from this project.

RESULTS

Journal Publications:

Koshak, William, Harold Peterson, Maudood Khan, Arastoo Biazar, Lihua Wang, 2012: The NASA Lightning Nitrogen Oxides Model (LNOM): Application to Air Quality Modeling. *Atmos. Res.* (Submitted)

Kuang, S., J. F. Burris, M. J. Newchurch, S. Johnson, S. Long (2010), Differential Absorption Lidar to Measure Sub-hourly Variation of Tropospheric Ozone Profiles, IEEE Trans. Geosci. Remote Sens., 49 (1), 557-571, ISSN: 0196-2892, DOI:10.1109/TGRS.2010.2054834

Kuang, Shi, M.J. Newchurch, John Burris, Lihua Wang, Patrick I. Buckley, Steve Johnson, Kevin Knupp, Guanyu Huang, Dustin Phillips, Wesley Cantrell (2011), Nocturnal ozone enhancement in the lower troposphere observed by lidar, *Atmos. Environ.*, Volume 45, Issue 33, Pages 6078-6084, ISSN 1352-2310, DOI: 10.1016/j.atmosenv.2011.07.038.

Mackaro, S., R.T. McNider, A. Biazar (2011), Some Physical and Computational Issues in Land Surface Data Assimilation of Satellite Skin Temperatures, Pure and Applied Geophysics, Vol. 167, No. 11, p. 1-14, Doi: 10.1007/s00024-011-0377-0. Url: http://dx.doi.org/10.1007/s00024-011-0377-0

Ngan, F., D. W. Byun, H. C. Kim, B. Rappenglueck and A. Pour-Biazar, 2012: Performance Assessment of Retrospective Meteorological Inputs for Use in Air Quality Modeling during TexAQS 2006. *Atmos. Environ.*, **54**, 86-96.

Pour-Biazar, A., M. Khan, L. Wang, Y. Park, M. Newchurch, R. T. McNider, X. Liu, D. W. Byun, and R. Cameron (2011), Utilization of satellite observation of ozone and aerosols in providing initial and boundary condition for regional air quality studies, J. Geophys. Res., 116, D18309, doi:10.1029/2010JD015200.

Wang L, M. J. Newchurch , A. Pour-Biazar , S. Kuang , M. Khan , X. Liu , W. Koshak , and K. Chance (2011), Estimating the Influence of Lightning on Upper Tropospheric Ozone Using NLDN Lightning Data and CMAQ model, J. Geophys. Res., submitted.

Wang, L., M. J. Newchurch, A. Biazar, X. Liu, S. Kuang, M. Khan, and K. Chance (2011), Evaluating AURA/OMI ozone profiles using ozonesonde data and EPA surface measurements for August 2006, Atmos. Environ., 45(31), 5523-5530.

RESULTS

Proceedings:

Koshak, William, Maudood Khan, Harold Peterson, Lihua Wang, Arastoo Biazar, The Lightning Nitrogen Oxides Model (LNOM): status and recent applications. 91st American Meteorological Society Meeting, Seattle, WA, January, 2011.

Koshak, W., H. Peterson, M. Khan, A. Biazar, L. Wang, The NASA Lightning Nitrogen Oxides Model (LNOM): Application to Air Quality Modeling, XIV International Conference on Atmospheric Electricity, Rio de Janeiro, Brazil, August 8-12, 2011.

Koshak, W., and H. Peterson, A summary of the NASA Lightning Nitrogen Oxides Model (LNOM) and recent results, 10th Annual Community Modeling and Analysis System (CMAS) Conference, Chapel Hill, NC, October 24-26, 2011.

Newchurch, Mike, J. Burris, S. Kuang, A. Pour Biazar, G. Huang, L. Wang, W. Cantrell, P. Buckley, R. Pierce, R. Hardesty, R.J. Alvarez, J.W. Hair, I.S. McDermid, T. McGee (2011), Spatio-Temporal Variability of Ozone in the Boundary Layer and Free Troposphere, *Abstract A21C-0087 presented at 2011 Fall Meeting, AGU, San Francisco, Calif., 5-9 Dec.*

Park, Yun-Hee, Arastoo Pour Biazar, Richard McNider, Kevin Doty, Bright Dornblaserr, Satellite Assimilation to Improve Cloud Prediction in WRF Model, *10th Annual CMAS Conference, Chapel Hill, NC, October 24-26, 2011*.

Pour Biazar, Arastoo, Maudood Khan, S. Kuang, Y. H. Park, L. Emmons, R. T. McNider, M. Newchurch, A Modeling Study Using WRF/CMAQ to Explain A Trpopause Folding Event Over the Gulf of Mexico, in *Proceedings of American Meteorological Society 92th Annual Meeting,*New Orleans, LA, 22-26 January 2012.

Pour Biazar, Arastoo, R. T. McNider, Y. - H. Park, K. Doty, B. Dornblaser, M. Khan, Cloud Assimilation in WRF, 16th International Conference on Clouds and Precipitation, ICCP-2012, 13.2 - Applications of cloud and precipitation physics, Leipzig University, Leipzig, Germany, July 30 – August 3, 2012.

Pour Biazar, Arastoo, Maudood Khan, S. Kuang, Yun-Hee Park, L.K. Emmons, Richard T. McNider, M. Newchurch (2011), Stratospheric Ozone Intrusion over the Gulf of Mexico, *Abstract A51A-0240 presented at 2011 Fall Meeting, AGU, San Francisco, Calif., 5-9 Dec.*

Pour Biazar,Arastoo, Richard T. McNider, Maudood Khan, Mike Newchurch, Xiong Liu, Yun-Hee Park, Lihua Wang, Daewon W. Byun (2010), Use of Ozone Monitoring Instrument (OMI) Ozone Profiles in Air Quality Assessment Studies, 30th European Association of Remote Sensing Laboratories (EARSeL) Symposium, UNESCO Headquarters, Paris, France, May 31-June 3, 2010.

Pour Biazar, Arastoo, R. T. McNider, K. Doty, Y. H. Park, M. Khan, Bright Dornblaser, Use of Geostationary Satellite Observations for Dynamical Support of Model Cloud Fields, *9th Annual CMAS Conference, Chapel Hill, NC, October 11-13, 2010*.

Pour Biazar, Arastoo, Maudood Khan, Yun-Hee Park, Richard T. McNider, Robert Cameron (2010), Improved Specification of Transboundary Air Pollution over the Gulf of Mexico Using Satellite Observations, Abstract A31B-0051 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec, 2010.

ACRONYMS

CMAQ	EPA's Community Multiscale Air Quality (CMAQ) Model
CMAS	Community Modeling and Analysis System
EPA	Environmental Protection Agency
LNOx	Lightning Generated Nitrogen Oxides
LNOM	Lightning Nitrogen Oxides Model
NASA	National Aeronautics and Space Administration
SIP	State Implementation Plan
TCEQ	Texas Commission on Environmental Quality

Thank You

Overview of the Data Archive & Delivery system

NSSTC Satellite Ground Station & Data Link

↓

NSSTC Satellite Data Processing & Product Generation

- Insolation
- Skin Temperature
- Surface Albedo
- Cloud Albedo
- Cloud Top Temperature/Pressure
- Cloud Transmittance
- MODIS Emissivity

↓

Web Based Satellite data delivery system (SAT_ASSIM.NSSTC.UAH.EDU)

- Archive and Distribute Data
- Regridding Software
- Data Processing Software

↓

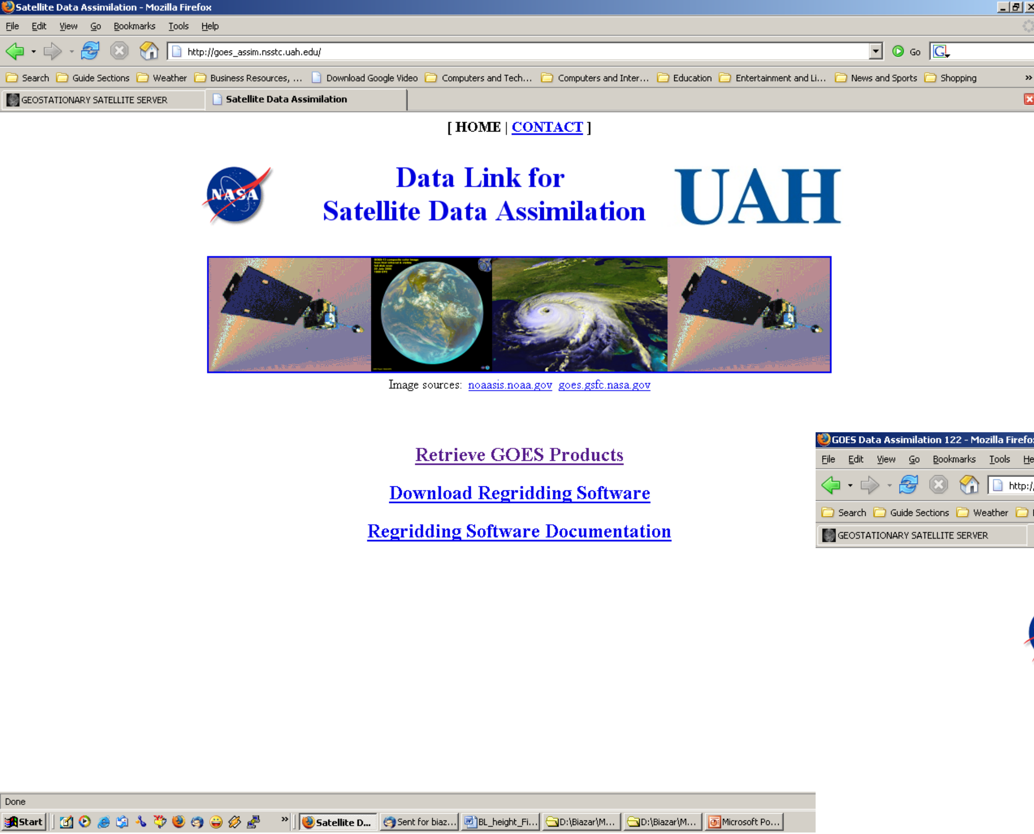
Decision Support Tools

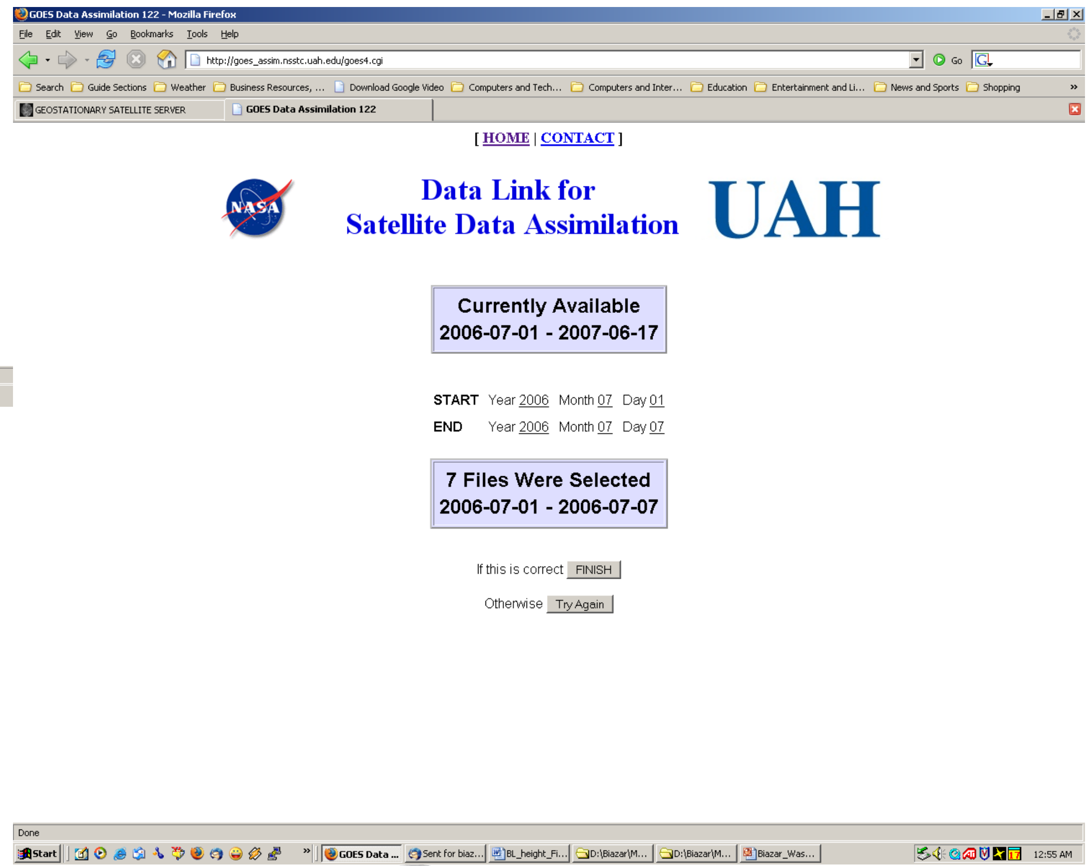
MM5/WRF → CMAQ/WRFCHEM

↓

State, Local & Private Sector Users

Web Based Delivery System





sat_assim.nsstc.uah.edu

Username: levl

Password: sparkx